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Research Article

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Effect of phosphorus, sulphur and phosphate solubilizing bacteria on yield, nutrient uptake and soil fertility after harvest of mustard

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Summary

A field experiment was conducted to evaluate the effect of phosphorus, sulphur and phosphate solubilizing bacteria on growth and nutrient uptake by mustard [*Brassica juncea* (L.) Czern and Cosson.] grown in loamy sand soil. The experimental soil has pH 7.60 and was deficient in available sulphur and nitrogen and medium in available phosphorus. The experiment was tested by Randomized Block Design with four replications. The treatments comprised of three levels each of phosphorus (0, 25, 50 kg P_2O_5 ha^{-1}) and sulphur (0, 20, 40 kg S ha^{-1}) and two levels of phosphate solubilizing bacteria (PSB) inoculation (no inoculation and inoculation with *Aspergillus niger* strain-1). The results of the experiment revealed that each successive increase in level of phosphorus significantly increased the crop growth and uptake of nutrients. Different levels of sulphur significantly improved the growth, yield as well as uptake of nutrients by seeds and straw of mustard. Seed inoculation with PSB (I_1) significantly increased yield, uptake in seed and straw and availability of nutrients in soil. Combined effect of 50 kg P_2O_5 ha^{-1} and 40 kg S ha^{-1} with seed inoculation with PSB gave higher seed and straw yield as well as nutrient content in seed and straw which resulted in higher nutrient uptake by mustard grown in loamy sand of North Gujarat.

Key words : Phosphorus, Sulphur, PSB, Yield, Uptake, Fertility mustard

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Introduction

The main objective of nutrient management strategies is to achieve the required crop yield in an efficient, economical and sustainable manner through removal of constraints including nutrient deficiencies; balanced fertilization has been the most important approach for the sustainable agriculture. Phosphorus has been referred as 'king pin' in Indian agriculture and is one of the 'big three' in crop nutrition. It is also referred as the 'master key' element in crop production. The occurrence of more than 60 per cent P deficient soil in Gujarat signifies the importance of P nutrition for sustainable agriculture (Patel *et al.*, 1998). The results of the long term fertilizer experiments clearly taught us the lesson that " if you wish to secure N efficiency, makes sure that there is no P deficiency". For these reasons, scientists are exploring new ways of meeting the nutrient needs of crop plants at high levels of productivity. Soil

bacteria of diverse kinds have a particular importance in exploration of these approaches. Irrespective of crops, sulphur is now rightly called the fourth major plant nutrient, next only to N, P and K but for oilseed crops it is as important as phosphorus. Use of high analysis sulphur free fertilizers, cultivation with high yielding varieties and neglect of S replenishment contributed to wide spread sulphur deficiencies in India. Because of anionic nature of phosphorus and sulphur in soil and plant system, there exists an interaction between these two nutrients. The interaction may be synergistic or antagonistic which depend on the extent of nutrient availability and the proportion of applied nutrients. Phosphate solubilizing micro-organisms are distributed well in several ecosystems. Fungi (*Aspergillus*, *Pencillium*, *Mucor*, *Fusarium*, *Candidi*, etc.), bacteria (*Bacillus*, *Pseudomonas*, *Micrococcus*, *Flavobacterium*) and actinomycetes (*Streptomyces*) have been isolated, which have consistent capacity to solubilize insoluble phosphorus such a rock phosphate, tricalcium phosphate, aluminum phosphate, iron phosphate, etc. These bacteria secrete non-volatile organic acids such as butyric, tartaric, aspartic, glutamic, lactic, citric, oxalic, glucolic, malic, fumaric and α-ketobutyric acids (Bardiya and Gaur, 1972; Gaur and Pareek, 1974) which lower down the pH and liberate bound phosphate. Besides, some of the hydroxy acids may chelate calcium and iron resulting in effective solubilization and thereby higher utilization of soil phosphates by plants. They also produce an enzyme phosphatase, which enhance the process of solubilization of insoluble phosphate. The available research findings regarding the interactive behaviours of P x S x PSB are scanty and inconclusive, so an attempt has been made to get a conclusive idea with respect to study the interrelationship between P, S and PSB on mustard grown on loamy sand of North Gujarat.

Resource and Research Methods

The field experiment was conducted at the Seed Technology-I farm of S.D. Agricultural University, Sardarkrushinagar (Gujarat) for two consecutive years (2007-08 and 2008-09). The experimental soil was loamy sand in texture, noncalcareous in nature, slightly alkaline in reaction (pH 7.6), normal with respect to salinity (EC 0.1 dSm^{-1}), low in organic carbon (0.17%), available nitrogen (238 kg ha^{-1}) and sulphur (8.8 mg kg^{-1}) and medium in available phosphorus (32.6 kg ha^{-1}). The experiment consisted of three levels each of phosphorus (0, 25, 50 kg P_2O_5 ha^{-1}) and sulphur (0, 20, 40 kg S ha^{-1}) and two levels of phosphate solubilizing bacteria (PSB) inoculation (no inoculation and inoculation with *Aspergillus niger* strain-1). During both the years, required quantity of phosphorus and sulphur as per their levels were applied through DAP and gypsum, respectively. The crop was fertilized with recommended dose of nitrogen *i.e.* 50 kg N ha^{-1}. Half dose of nitrogen was applied as basal through urea and DAP and remaining half dose was applied as top dressing through urea at 30 days after sowing. The pure and freshly prepared strains of phosphate solubilizing fungi (*Aspergillus niger* strain-1) having a population of 1×10^8 colony forming units (CFU) per gram of carrier obtained from Department of Microbiology, C.P. College of Agriculture, Sardarkrushinagar were brought and inoculants of *Aspergillus niger* @ 30 g kg^{-1} of seed were mixed and coated uniformly and used for sowing as per treatment. All the packages of practices were followed as per recommendations. After harvesting of mustard, the seed and straw samples were collected and analyzed for N, P K and S contents using the standard procedures given by Jackson (1973). The uptake of nutrients was calculated by multiplying their content with corresponding values of yield. To assess the fertility status of soil at harvest, a representative soil samples (0-15 cm depth) from each plot after harvest of mustard crop for both the years were collected with the help of auger and analyzed for available N, P and S status in soil as employing suitable methods.

Research Findings and Discussion

The results obtained from the present investigation as well as relevant discussion have been summarized under following heads :

Seed and straw yield of mustard :

Effect of phosphorus :

The results on yield of mustard showed that application of different P levels significantly affected during both the years and in pooled.

Application of 50 kg P_2O_5 ha^{-1} (P_2) noticed significantly the highest seed yield of 1966, 1833 and 1900 kg ha^{-1} in first year, second year and pooled result, respectively. While, highest straw yield was recorded with P_2 level (50 kg P_2O_5 ha^{-1}) and it was 20.4, 22.6 and 21.5 per cent higher as compared to P_0 (control) and P_1

(25 kg P_2O_5 ha^{-1}) in first year, second year and pooled, respectively (Table 1).

The beneficial effect of P on yield attributing characters could be ascribed to fact that enhanced activity of growth and more flowering and pod setting as P stimulates the flowering and seed formation (Yawalker *et al.*, 1996) and also producing bold sized seeds with more accumulation of photosynthates. Moreover, cumulative effect on improvement in all growth and yield attributing characters under P treatment might have contributed for the increase in the yields of mustard. The results are in conformity with the findings of Yadav *et al.* (2014); Ram *et al.* (2011); Khatkar *et al.* (2009); Patel (2000); Sahu *et al*. (2004) and Lanjewar and Selukar (2005).

Effect of sulphur :

The effect of different S levels on seed and straw yield of mustard were significant at both the years and in pooled. The application of 40 kg S ha^{-1} (S_2) produced significantly maximum seed yield of 1951, 1807 and 1879 kg ha^{-1} in first year, second year and pooled, respectively. Similarly, an application of 40 kg S ha^{-1} (S_2) registered significantly the highest straw yield (4192, 3989 and 4091 kg ha^{-1}) during both the years and in pooled, which was 19.5, 18.3 and 18.9 per cent higher over S_0 level, respectively (Table 1). Such a positive effect of S application might be due to better chlorophyll synthesis through sulphur nutrition, which in turn increases the effective area for photosynthesis, which reflects in terms of increased yield attributes of crop. These finding are in accordance with those reported by Kour *et al.* (2014); Dubey *et al.* (2013); Jat and Mehra (2007); Bansal *et al*. (2000); Kumar *et al*. (2001); Misra (2003); Dongarkar *et al*. (2005) and Singh *et al*. (2008) in mustard.

Effect of PSB inoculation :

The application of phosphate solublizing bacteria significantly affected the seed and straw yield of mustard in individual years and pooled. The application of I_1 (*Aspergillus niger* strain-1) treatment produced the significantly highest seed (1787, 1633 and 1710 kg ha^{-1}) and straw yield (3972, 3818 and 3895 kg ha^{-1}) of mustard in both the individual year and pooled, respectively. The per cent increase in straw yield due to I_1 over I_0 was 5.7, 6.1 and 5.9 in first year, second year and pooled, respectively (Table 1). The beneficial effect of PSB in present study could be attributed to the fact that PSB

Table 1 : Effect of P, S and PSB on seed and straw yield of mustard

Treatments	Seed yield (kg ha^{-1})			Straw yield (kg ha^{-1})		
	Ist year	IInd year	Pooled	Ist year	IInd year	Pooled
Phosphorus						
P_0	1472	1341	1406	3499	3318	3409
P_1	1700	1558	1629	3880	3736	3808
P_2	1966	1833	1900	4214	4068	4141
S.E.±	41	33	26	79	94	62
C.D. (P=0.05)	116	94	74	225	268	173
Sulphur						
S_0	1474	1351	1413	3508	3372	3440
S_1	1713	1574	1643	3894	3760	3827
S_2	1951	1807	1879	4192	3989	4091
S.E.±	41	33	26	79	94	62
C.D. (P=0.05)	116	94	74	225	268	173
PSB						
I_0	1639	1521	1580	3757	3597	3677
I_1	1787	1633	1710	3972	3818	3895
S.E.±	33	27	21	65	77	50
C.D. (P=0.05)	95	77	60	184	219	142
Significant interaction	P × S	P × S	P × S	P × S	-	P × S
C.V.%	12	10	11	10	12	11

solubilizes the native as well as applied phosphorus and also synthesize growth promoting substances like auxin, indole acetic acid, gibberellins, cytokinin and vitamins which augment the plant growth (Subbarao,1986). Similar beneficial effect of PSB inoculation on yield of mustard was also reported by Ram and Pareek (2000); Kantwa and Meena (2002); Vyas (2003) and Gudadhe *et al*. (2005) in mustard.

Interaction effect :

The interaction effect of P × S was significant on seed and straw yield (Table 2) during both the years and in pooled analysis. The data revealed that combined application of P @ 50 kg P_2O_5 ha^{-1} and S @ 40 kg S ha^{-1} gave maximum seed yield (2066, 2024 and 2045 kg ha^{-1} in first year, second year and pooled data, respectively) and it was at par with treatment combinations P_2S_1 and P_1S_2 during first year and P_2S_1 during second year and in pooled analysis. Similarly the treatment combination P_2S_2 (50 kg P_2O_5 + 40 kg S ha^{-1}) noticed maximum straw yield (4371 and 4323 kg ha^{-1} in first year and pooled analysis, respectively) of mustard and it was at par with treatment combinations P_2S_1, P_2S_0 and P_1S_2 during first year and P_2S_1 and P_1S_2 in pooled results (Table 1). The beneficial effect of P × S interaction has been reported by Kumar and Yadav (2007) and Patel *et al.* (1998).

Nutrients uptake by seed and straw of mustard :

Effect of phosphorus :

The data on uptake of nutrients by seed and straw are presented in Tables 3 to 6 which showed significant effect on nutrients content and uptake by seed and straw due to different levels of P. Application of 50 kg P_2O_5 ha^{-1} (P_2) resulted significantly higher values of N, P, K and S uptake by seed and straw of mustard during both the years and in pooled analysis. The considerable increase in nutrient uptake by seed and straw could be attributed to the fact that P stimulate the early root development and growth and there by efficient utilization of nutrients from the deeper soil layer. A significant influence on these nutrient uptakes by seed and straw due to increase in concentration along with increase in yield of seed and straw. The results of investigation are in close agreement with those reported by Ram *et al.* (2011); Patel (2000); Davaria *et al*. (2001); Lanjewar and Selukar (2005) and Ghadge *et al*. (2005) in mustard.

Table 2 : Effect of P × S interaction on seed and straw yield of mustard

Phosphorus levels	Seed yield (kg ha^{-1})			Straw yield (kg ha^{-1})		
	Sulphur levels			Sulphur levels		
	S_0	S_1	S_2	S_0	S_1	S_2
Ist year						
P_0	1160	1456	1800	2877	3609	4012
P_1	1409	1703	1986	3568	3880	4193
P_2	1854	1979	2066	4079	4193	4371
S.E.±		71			137	
C.D. (P=0.05)		201			390	
IInd year						
P_0	1054	1334	1634	2820	3427	3708
P_1	1435	1478	1763	3436	3785	3986
P_2	1565	1909	2024	3860	4070	4275
S.E.±		57			163	
C.D.(P=0.05)		163			NS	
Pooled						
P_0	1107	1395	1717	2849	3518	3860
P_1	1422	1590	1875	3502	3832	4089
P_2	1710	1944	2045	3970	4131	4323
S.E.±		45			107	
C.D.(P=0.05)		128			300	

NS= Non-significant

Effect of sulphur :

The uptake of nutrients (N, P, K and S) by seed and straw were improved significantly due to application of 40 kg S ha^{-1} (S_2), over control (S_0) and 20 kg S ha^{-1} (S_1) during both the years and in pooled also. The significant increase in uptake of nutrients by sulphur application might be due to sulphur deficiency in experimental soil which may be attributed to profuse vegetative and root growth, there by activating absorption of nutrients, which in turn increased the concentration of nutrients and dry matter accumulation. These results are in conformity with the results of Kour *et al*. (2014); Ram *et al*. (2011); Jat and Mehra (2007); Patel (2000); Tripathi and Joshi (2001); Misra (2003); Parmar (2003) and Kapur (2004) in mustard.

Effect of PSB inoculation :

The results clearly indicated that inoculation treatment (I_1) significantly increased the N, P, K and S uptake by seed and straw during both the years of investigation as well as in pooled analysis. Seed inoculation with PSB considerably enhanced the uptake of nutrients by seed and straw probably due to increased availability of P by solubilization of native phosphorus which reflected into profuse root growth and development and there by increase in root traversing area in soil to facilitate more absorption of nutrients. Since uptake of nutrients is a product of seed and straw yield and their nutrient content, the significant improvement in nutrients uptakes by seed and straw due to increase in seed and straw yield. The beneficial effect of PSB had also been reported by Dubey *et al*. (1997) and Ram and Pareek (2000) in mustard.

Interaction effect :

The results of the study revealed that combined application of P and S improved the nutrients uptake by seed and straw during both the years of investigation and in pooled results (Table 7). Significantly the maximum uptake of N and P by seed during second year and P uptake by straw during first year were noted with the treatment combination P_2S_2. Similar trend was observed for K and S. The significant interactive effect of P and S on nutrients content and uptake might be due to improvement in the over all nutritional environments in whole plant system and enhanced the plant growth by promoting meristematic activity and dry matter accumulation. The results obtained during investigation

Table 3 : Effect of P, S and PSB on nitrogen uptake by seed and straw of mustard

Treatments	N uptake by seed (kg ha^{-1})			N uptake by straw (kg ha^{-1})		
	I^{st} year	II^{nd} year	Pooled	I^{st} year	II^{nd} year	Pooled
Phosphorus						
P_0	44.25	39.70	41.98	15.37	15.19	15.28
P_1	54.16	47.98	51.07	18.41	19.27	18.84
P_2	65.16	59.33	62.24	21.99	22.69	22.34
S.E.±	1.469	1.035	0.899	0.466	0.585	0.374
C.D. (P=0.05)	4.175	2.943	2.529	1.324	1.662	1.052
Sulphur						
S_0	44.91	40.16	45.54	15.69	15.88	15.78
S_1	54.31	48.83	51.57	18.55	19.08	18.82
S_2	64.35	58.03	61.19	21.53	22.19	21.86
S.E.±	1.469	1.035	0.899	0.466	0.585	0.374
C.D. (P=0.05)	4.175	2.943	2.529	1.324	1.662	1.052
PSB						
I_0	51.52	46.49	49.00	17.68	17.97	17.83
I_1	57.53	51.52	54.52	19.50	20.12	19.81
S.E.±	1.199	0.845	0.734	0.380	0.447	0.305
C.D. (P=0.05)	3.409	2.403	2.065	1.081	1.357	0.858
Significant interaction	-	P × S	-	-	-	-
C.V.%	13.20	10.35	12.03	12.28	15.04	13.76

are in conformity with those reported by Kharodia (1997) and Patel (2000) in mustard.

Interaction effect of PSB × P was also found synergistic on P and S content in straw during first year and in pooled analysis, respectively. The application of 50 kg P_2O_5 ha^{-1} with seed inoculation with PSB produced significantly the highest P and S content in straw of mustard. This might be due to PSB play a vital role in solubilization of added phosphorus through producing organic acid and enzymes. Similar results were also reported by Dubey *et al*. (1997) in mustard.

Soil status at the time of harvest of mustard :

Effect of phosphorus :

The application of P @ 50 kg P_2O_5 ha^{-1} significantly enhanced the available N, P and S in soil during both the years and in pooled analysis (Table 8). These might be due to enhanced microbial activity by P application in rhizosphere through development of fibrous and deep root system of plant there by recycled the nutrients from deeper layer to upper layer of soil. Similar results were observed by Patel (2000) and Ghadge *et al*. (2005) after harvest of mustard.

Effect of sulphur :

Sulphur application @ 40 kg S ha^{-1} significantly increased the available N, P and S in soil at harvest during both the years of study and in pooled analysis. The increase in available nutrient status in soil with S application might be due to stimulating effect of sulphur on mineralization of nutrients in soil and provide favorable condition for microbial activity as well as chemical activity, which resulted higher availability of nutrients in soil. These results are in line with the earlier findings of Patel (2000); Akbari *et al*. (2003) and Ghadge *et al*. (2005) after harvest of mustard.

Effect of PSB inoculation :

Inoculation with PSB (I_1) significantly increased the available N, P and S in soil during both the years and in pooled analysis except available N in soil during second year. These could be attributed due to release of some organic acids and enzymes by PSB in soil and resulted in favourable conditions in rhizosphere and there by enhance nutrient availability. The findings are in close agreement with those obtained by Patel (2004) after harvest of green gram.

Table 4 : Effect of P, S and PSB on phosphorus uptake by seed and straw of mustard

Treatments	P uptake by seed (kg ha^{-1})			P uptake by straw (kg ha^{-1})		
	I^{st} year	II^{nd} year	Pooled	I^{st} year	II^{nd} year	Pooled
Phosphorus						
P_0	7.37	7.31	7.34	5.89	6.33	6.11
P_1	9.97	9.43	9.70	8.55	8.56	8.55
P_2	12.87	12.31	12.59	10.57	11.13	10.85
S.E.±	0.257	0.210	0.166	0.166	0.262	0.155
C.D. (P=0.05)	0.731	0.598	0.468	0.471	0.744	0.436
Sulphur						
S_0	7.97	7.59	7.78	6.34	6.71	6.53
S_1	10.02	9.63	9.82	8.40	8.83	8.61
S_2	12.22	11.83	12.02	10.26	10.48	10.37
S.E.±	0.257	0.210	0.166	0.166	0.262	0.155
C.D. (P=0.05)	0.731	0.598	0.468	0.471	0.744	0.436
PSB						
I_0	9.40	9.09	9.25	7.57	7.83	7.70
I_1	10.74	10.27	10.51	9.10	9.52	9.31
S.E.±	0.210	0.172	0.136	0.135	0.214	0.127
C.D. (P=0.05)	0.597	0.488	0.382	0.385	0.608	0.356
Significant interaction	-	P × S	-	P × S	-	-
C.V.%	12.51	10.65	11.66	9.75	14.79	12.62

Table 5 : Effect of P, S and PSB on potassium uptake by seed and straw of mustard

Treatments	K uptake by seed (kg ha^{-1})			K uptake by straw (kg ha^{-1})		
	Ist year	IInd year	Pooled	Ist year	IInd year	Pooled
Phosphorus						
P_0	12.73	11.91	12.32	41.26	40.76	41.01
P_1	15.14	14.42	14.78	46.94	47.22	47.08
P_2	18.50	17.75	18.12	52.85	53.18	53.02
S.E.±	0.340	0.324	0.235	1.139	1.126	0.801
C.D. (P=0.05)	0.966	0.921	0.661	3.237	3.201	2.253
Sulphur						
S_0	12.77	12.04	12.40	41.54	41.27	41.04
S_1	15.37	14.58	14.97	47.42	47.95	47.69
S_2	18.23	17.45	17.84	52.09	51.94	52.01
S.E.±	0.340	0.324	0.235	1.139	1.126	0.801
C.D. (P=0.05)	0.966	0.921	0.661	3.237	3.201	2.253
PSB						
I_0	14.65	13.90	14.27	45.43	45.29	45.36
I_1	16.26	15.48	15.87	48.60	48.82	48.71
S.E.±	0.277	0.265	0.192	0.930	0.919	0.654
C.D. (P=0.05)	0.789	0.752	0.539	2.643	2.613	1.840
Significant interaction	P × S	-	P × S	-	-	-
C.V.%	10.77	10.80	10.79	11.87	11.72	11.79

Table 6 : Effect of P, S and PSB on sulphur uptake by seed and straw of mustard

Treatments	S uptake by seed (kg ha^{-1})			S uptake by straw (kg ha^{-1})		
	Ist year	IInd year	Pooled	Ist year	IInd year	Pooled
Phosphorus						
P_0	18.88	17.69	18.28	8.15	8.82	8.49
P_1	22.66	21.14	21.90	10.72	11.64	11.18
P_2	26.93	25.71	26.32	13.41	14.20	13.80
S.E.±	0.593	0.462	0.376	0.239	0.356	0.214
C.D. (P=0.05)	1.687	1.313	1.058	0.678	1.012	0.603
Sulphur						
S_0	18.84	17.66	18.25	7.99	8.99	8.49
S_1	22.78	21.36	22.07	10.94	11.70	11.32
S_2	26.85	25.51	26.18	13.35	13.97	13.66
S.E.±	0.593	0.462	0.376	0.239	0.356	0.214
C.D. (P=0.05)	1.687	1.313	1.058	0.678	1.012	0.603
PSB						
I_0	21.60	20.58	21.09	9.90	10.69	10.30
I_1	24.04	22.44	23.24	11.62	12.41	12.01
S.E.±	0.484	0.377	0.307	0.195	0.291	0.175
C.D. (P=0.05)	1.377	1.072	0.864	0.554	0.826	0.492
Significant interaction	P × S	-	P × S	-	-	-
C.V.%	12.74	10.52	11.75	10.86	15.09	13.21

Table 7 : Effect of P × S interaction on nutrients uptake by seed/straw of mustard

Phosphorus levels	N uptake by seed (kg ha^{-1})		
	Sulphur levels		
	S_0	S_1	S_2
IInd year			
P_0	28.62	39.88	50.58
P_1	42.93	45.06	55.95
P_2	48.92	61.54	67.55
S.E.±		1.793	
C.D. (P=0.05)		5.096	
P uptake by seed (kg ha^{-1})			
IInd year			
P_0	5.02	7.35	9.55
P_1	8.04	8.80	11.46
P_2	9.71	12.74	14.47
S.E.±		0.365	
C.D. (P=0.05)		1.037	
P uptake by straw (kg ha^{-1})			
Ist year			
P_0	3.44	5.98	8.25
P_1	6.41	8.73	10.49
P_2	9.17	10.50	12.03
S.E.±		0.287	
C.D. (P=0.05)		0.816	
K uptake by seed (kg ha^{-1})			
Ist year			
P_0	9.40	12.58	16.21
P_1	12.03	14.93	18.45
P_2	16.87	18.59	20.03
S.E.±		0.589	
C.D. (P=0.05)		1.674	
Pooled			
P_0	9.08	12.13	15.75
P_1	12.37	14.26	17.70
P_2	15.76	18.53	20.08
S.E.±		0.407	
C.D. (P=0.05)		1.144	
S uptake by seed (kg ha^{-1})			
Ist year			
P_0	13.78	18.68	24.19
P_1	17.96	22.64	27.39
P_2	24.80	27.02	28.97
S.E.±		1.028	
C.D. (P=0.05)		2.922	
Pooled			
P_0	13.40	18.08	23.37
P_1	18.27	21.30	26.13
P_2	23.09	26.82	29.05
S.E.±		0.651	
C.D. (P=0.05)		1.833	

Table 8 : Effect of P, S and PSB on availability of nitrogen in soil

Treatments	Available N (kg ha^{-1})			Available P_2O_5 (kg ha^{-1})			Available S (mg kg^{-1})		
	Ist year	IInd year	Pooled	Ist year	IInd year	Pooled	Ist year	IInd year	Pooled
Phosphorus									
P_0	232.5	223.5	228.0	28.68	32.55	30.61	10.85	9.64	10.24
P_1	238.0	229.6	233.8	33.24	37.17	35.20	12.85	11.83	12.34
P_2	241.9	233.5	237.7	40.95	40.35	40.65	13.99	13.08	13.53
S.E.±	1.4	1.1	0.9	0.238	0.324	0.201	0.105	0.111	0.076
C.D. (P=0.05)	3.8	3.3	2.5	0.677	0.922	0.566	0.298	0.316	0.215
Sulphur									
S_0	235.0	225.6	230.3	32.58	34.97	33.77	8.89	8.32	8.61
S_1	237.4	229.1	233.2	34.31	36.84	35.57	12.42	12.03	12.22
S_2	240.0	231.9	235.9	35.98	38.26	37.12	16.37	14.20	15.29
S.E.±	1.4	1.1	0.9	0.238	0.324	0.201	0.105	0.111	0.076
C.D. (P=0.05)	3.8	3.3	2.5	0.677	0.922	0.566	0.298	0.316	0.215
PSB									
I_0	235.4	227.7	231.5	33.39	35.29	34.34	12.28	11.11	11.69
I_1	239.6	230.0	234.8	35.19	38.09	36.64	12.84	11.92	12.38
S.E.±	1.1	0.9	0.7	0.194	0.265	0.164	0.086	0.091	0.062
C.D. (P=0.05)	3.1	NS	2.0	0.553	0.753	0.462	0.243	0.258	0.176
Significant interaction	-	-	-	P × S	-	-	P × S	P × S	P × S
C.V.%	2.8	2.5	2.6	3.40	4.33	3.93	4.09	4.73	4.40

NS= Non-significant

Table 9 : Effect of P × S interaction on available phosphorus and sulphur in soil

Phosphorus levels	Available P_2O_5 (kg ha^{-1})		
	Sulphur levels		
	S_0	S_1	S_2
Ist year			
P_0	26.82	28.66	30.56
P_1	32.38	33.15	34.18
P_2	38.53	41.11	43.21
S.E.±		0.412	
C.D. (P=0.05)		1.171	
Available S in soil (mg kg^{-1})			
Ist year			
P_0	7.61	10.16	14.77
P_1	9.17	12.72	16.64
P_2	9.89	14.38	17.70
S.E.±		0.182	
C.D. (P=0.05)		0.517	
IInd year			
P_0	7.15	9.61	12.15
P_1	8.41	12.39	14.70
P_2	9.40	14.08	15.75
S.E.±		0.193	
C.D. (P=0.05)		0.548	
Pooled			
P_0	7.38	9.88	13.46
P_1	8.79	12.56	15.67
P_2	9.65	14.23	16.72
S.E.±		0.132	
C.D. (P=0.05)		0.373	

Interaction effect :

Among the different interactions, P × S interaction was found to be significant in case of available P in soil during first year and available S in soil during both the years and in pooled analysis (Table 9). The treatment combination P_2S_2 (50 kg P_2O_5 + 40 kg S ha^{-1}) showed the highest values of available P and S status in soil. These might be due to synergistic effect of P and S on each other. Similar results were observed by Randhawa and Arora (1997).

Conclusion :

The application of 50 kg P_2O_5 ha^{-1}, 40 kg S ha^{-1} and inoculation of PSB (*Aspergillus niger*) individually increased yield and nutrient uptake by mustard, however, combined application of 50 kg P_2O_5 ha^{-1} along with 40 kg S ha^{-1} gave the higher yield and nutrients uptake by mustard as well as maintain soil fertility.

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